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Effect of Compost Addition on the Physical and Hydraulic Properties of Gypsiferous Soil under Field Irrigation Conditions

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ABSTRACT

This study aimed to evaluate the effect of compost addition on the hydraulic and physical properties of gypsiferous soils under field irrigation conditions. Two experimental sites were selected within the University of Tikrit area, Iraq, characterized by high gypsum content and similar climatic conditions. Compost (mixture of animal manure and plant residues) was applied at five rates (0, 2.5, 5, 7, and 10 t ha-1) and soil samples were analyzed for bulk density, total porosity, and saturated hydraulic conductivity at a depth of 0-30 cm. Results revealed that compost significantly improved soil physical conditions. Bulk density decreased gradually with increasing compost rate, reaching a reduction of about 11% at 10 t ha-1, while total porosity increased correspondingly by approximately 17%. These improvements were attributed to enhanced soil aggregation and organic matter incorporation that reduced compaction and increased pore continuity. Conversely, saturated hydraulic conductivity showed a gradual decline with increasing compost levels, suggesting partial blockage of macropores and increased water retention capacity. Data were statistically analyzed using analysis of variance (ANOVA), and significant differences among treatments were determined at the 0.05 probability level. Overall, compost application improved soil structure and porosity, while moderating water movement through the soil profile. The findings emphasize that moderate compost additions (5-7 t ha-1) achieve optimal balance between improved soil structure and acceptable water transmission, making compost a sustainable amendment for managing gypsiferous soils under irrigation in arid and semi-arid regions.

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KEYWORDS: Compost Application, Gypsiferous Soil, Bulk Density, Total Porosity, Hydraulic Conductivity.

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1. INTRODUCTION

Gypsous soils are found over wide areas of arid lands, in Iraq and the Middle East. These are highly calcareous soils and may contain large volumes of $CaSO_4 \cdot 2H2O$, which has a great effect on the behavior of these soils when wetted. When water comes into contact with such soils, the gypsum is easily solubilized, leading to changes in soil porosity and structure as well as water flow. With time, this manner of loosening can eventually result in weak aggregation, surface crusting and reduced water-holding capacity which may subsequently reduce soil productivity and irrigation efficiency (Al-Haidary et al., 2023; Hasson et al., 2024).

Farmers and soil scientists are well aware that the productivity of a gypsous field declines unless organic matter content is maintained. Frequent irrigation induces the gypsum leaching and aggravates the compaction problems (Mohammed and Ali, 2022). The problems are reduced by the addition compost. Compost improves soil aggregation, increases the continuity of pores and decreases the bulk density, thus improving water infiltrability and aeration (Abdullah et al., 2023; Iraji et al., 2025). The effect of livestock manure on soil properties is not limited to improvement in its physical and chemical condition (Haque et al., 2015; Haque et al., 2018). It increases the content of organic carbon and activity of microorganisms in soil, which can form the stable-sized aggregates and regulate soil balance as well. These benefits are especially important in gypsous areas where it slows the dissolution of gypsum and keeps a uniform distribution of water during irrigation (Fernandez et al., 2023; Rahman et al., 2023).

When compost is incorporated into the soil, it can help to improve water retention and avoid the fast changes in the usually observed water potential after irrigation (Wang et al., 2024). The improvement of the physical and hydraulic properties of gypsum-affected soils treated with compost or other organic material has been reported in many investigations. For instance, al-Dulaimi et al. (2024) demonstrated that co-application of Livestock manure and biochar, Bigne et al., tenía una demanda similar, A helicopter was used as the lifting media to transport materials up. Similarly, Saad et al. (2024), organic amendments decreased the bulk density and increased available water in gypsous soil under different irrigation treatments. Correspondingly, Tian et al. (2024) have explored a joint application of gypsum and organic matter as an effective management practice to improve the soil quality and yield of corn in semi-arid farmlands. These contributions emphasise the importance of organic amendments for maintaining fertility in gypsum-affected regions.

However, most studies were conducted under laboratory or potting conditions, where water movement is simple and does not fully reflect what occurs in the field. In real irrigation systems, the interactions between plaster solution, degradation of organic matter and soil moisture dynamics are more complex and less predictable (Rahman et al., 2023; Abdullah et al., 2023). Therefore, it is necessary to evaluate the performance of livestock manure during actual field watering to understand its actual effect on the physical and hydraulic behavior of the earth.

This study assesses how composting affects essential soil properties-bulk density, porosity, aggregate stability, infiltration, and water retention in gipsiferous soil during field watering. The results are expected to provide practical guidance to handle plaster -rich soil and improve water use efficiency in dry agricultural systems.

2. MATERIALS AND METHODS

2.1 Study area and soil characteristics

The field experiment was carried out during the 2024–2025 growing season at two locations: L1 (Agricultural Research Station) and L2 (Horticultural Establishment Station). situated within the University of Tikrit, Salah Al-Din Governorate, Iraq (34°36′ N, 43°41′ E). The region is characterized by a semi-arid climate, with mean annual rainfall of approximately 180 mm, mostly occurring between November and March, and an average yearly temperature ranging from 22 to 24 °C.

Both sites represent typical gypsiferous soils of central Iraq, formed under arid conditions showing a weak aggregation potential and high free $CaCO_3$ and gypsum contents as well as very low organic matter content. Before compost application, composite soil samples (0-30 cm) were randomly collected from each site, air-dried, and passed through a 2-mm sieve for the determination of the initial physical and chemical properties by common methods (Gee and Or, 2002; Klute and Dirksen, 1986).

Results As shown in Table 1, the soils at both locations were moderate in gypsum-, slightly-alkaline- and salinity degree. The bulk density and total porosity correspond to compact soil structure, and the saturated hydraulic conductivity indicates a moderate rate of water flow with restricted exchange among wetted channels. Organic matter was low (< 1%), for soil structure and hydraulic stability required a source of organic amendments.

Table (1): Initial physical and chemical properties of the gypsiferous soil at the two study locations before compost application.

Parameters	Unit	L1 (Agricultural Research Station)	L2 (Horticultural Establishment Station)
Bulk density (Pb)	$g.cm^{-3}$	1.51	1.53
Particle density (Ps)	$g.cm^{-3}$	2.50	2.50
Total porosity	%	39.6	38.8
Saturated Hydraulic	cm.min-1	1.42	1.38
pH	-	7.12	7.23
Electrical Conductivity (EC)	$dS.m^{-1}$	5.53	5.82
CEC	$cmol.kg^{-1}$	23.43	21.56
Gypsum Content	%	14.34	17.43
Organic Matter	%	0.52	0.64
($CaCO_3$)	$g.kg^{-1}$	189.58	195.87

2.2 Compost material and its properties

The compost used in this study was prepared from a mixture of animal manure and plant residues (mainly crop straw and date palm wastes) collected from the University of Tikrit farm. The material was composted under aerobic conditions for 90 days with regular turning and moisture adjustment (≈ 60% water content). During the maturation process, compost quality was monitored through temperature stabilization, absence of unpleasant odor, and a dark, humified appearance, indicating full maturity. After maturity, the compost was air-dried and sieved (< 5 mm) prior to field application.

Chemical analysis of the compost was performed to determine its key properties, including pH, electrical conductivity (EC), organic carbon, total nitrogen, phosphorus, potassium, and the C:N ratio (Page et al., 1982). The results are summarized in Table 2.

Table (2): Physico and chemical properties of the compost used in the experiment.

Parameter	Unit	Value
pH	–	7.3
Electrical conductivity (EC)	dS m^{-1}	4.2
Organic carbon	%	21.6
Total nitrogen	%	1.25
Total phosphorus (P)	%	0.68
Total potassium (K)	%	1.47
C:N ratio	–	17
Moisture content	%	27.5
Organic matter	%	37.3

composition and a suitable C: N ratio for field incorporation, indicating complete decomposition and good maturity.

2.3 Experimental design and treatments

The field experiment followed a Randomized Complete Block Design (RCBD) with three replications at each site. The main treatment factor was the compost application rate at five levels: (0, 2.5, 5.0, 7.0 and 10.0 t ha^{-1}). Compost was evenly broadcast and incorporated into the surface layer (0–30 cm) two weeks before sowing and irrigation. Each experimental plot measured 3 m × 3 m and was separated by 1 m buffer strips to minimize lateral water movement between plots.

2.4 Irrigation and field management

Irrigation water was supplied from the university's main canal, classified as moderately saline (EC ≈ 1.2 dS m^{-1}). The irrigation schedule was managed to maintain soil moisture near field capacity during the experimental period. Uniform field practices were applied to all plots, including tillage, leveling, and weed control, to ensure consistency across treatments.

2.5 Soil sampling and laboratory analyses

After 90 days of compost application, undisturbed soil samples were collected from each plot at the 0–30 cm depth using stainless-steel core cylinders (100 cm^3) to determine the main physical and hydraulic parameters:

Bulk density (Pd) was measured by the core method after oven-drying at 105 °C (Blake & Hartge, 1986).

Particle density (Pd) was determined by the pycnometer method.

The total porosity was calculated in Black (1965) by applying the following equation.

$$P\% = (1-(pb/ps))\times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

P= Porosity (%).

Pd= Bulk density (Mg m^{-3}).

Ps= particle density(Mg m^{-3}).

Saturated hydraulic conductivity:

The saturated water conductivity was measured using the fixed water column method proposedby Klute and described in Black (1965).

$$Ks = \frac{Q \times L}{A \times h \times t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Ks = Saturated Hydraulic Conductivity (cm h^{-1}).

Q = Discharge volume of water passing through the soil column (cm^3).

L = length of the column of soil (cm).

A = Area (surface) of the soil column (cm^2).

T = Time (min).

h = Height of the column + Depth of the water above the column (cm).

3. RESULTS AND DISCUSSION

3.1 Effect of compost application on bulk density

The results presented in Table 3 and Figure 1 show a clear and consistent decrease in soil bulk density (Pd) with increasing compost application rates at both locations. The control treatment (0 t ha^{-1}) recorded the highest PD values (1.51 and 1.53 g cm^{-3} at

L1 and L2, respectively), while the lowest PD values (1.34 and 1.36 g cm^{-3}) were observed at the highest compost rate of 10 t ha^{-1}. The reduction percentages relative to the control reached 11.3% at L1 and 11.1% at L2.

Table (3): Effect of compost levels on bulk density (g cm^{-3}) of gypsiferous soil under field conditions.

Site	Compost rate (t ha^{-1})	Bulk Density (mean) [g cm^{-3}]	SD	% change vs control	Significance
L1	0 (Control)	1.51	0.02	—	a
	2.5	1.48	0.03	−2.0	ab
	5.0	1.43	0.02	−5.3	b
	7.0	1.39	0.03	−7.9	bc
	10.0	1.34	0.03	−11.3	c
L2	0 (Control)	1.53	0.03	—	a
	2.5	1.49	0.02	−2.6	ab
	5.0	1.45	0.03	−5.2	b
	7.0	1.41	0.02	−7.8	bc
	10.0	1.36	0.03	−11.1	c

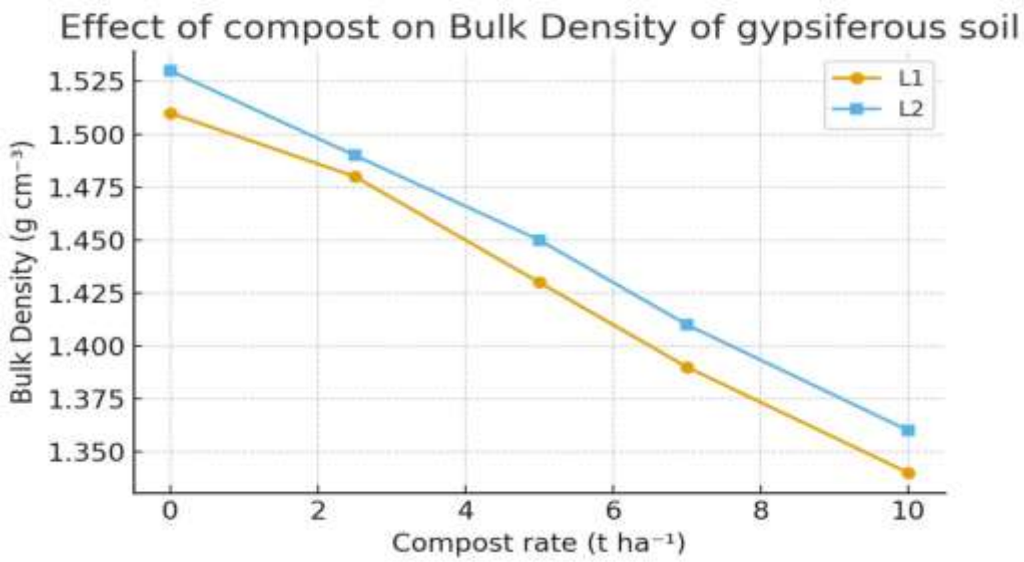

Figure (1): Effect of compost levels on bulk density of gypsiferous soil at two sites (L1 and L2).

The consistently decreasing trend of soil bulk density with increasing application level of livestock manure indicated the improvement of soil physical properties and structure stability. Compost application to soil richens the organic matter material and increases aggregation by becoming in a natural glue, which sticks mineral particles together and creates more extensive pore space (Kranz et al., 2020; Castellini et al., 2022). More than 10% decrease under the highest compost rate reveals that organic amendments allow for addressing compaction problems commonly associated with Gypsy soil. This was in accordance with the results of Bybil et al. (2022) that observed a 9-12% decline in Pd after the application of compost to dry soil. Likewise, Amer et al. (2023) demonstrated that organic matter contributes to breaking compacted soil layers and increasing air space in the roots zone. Such effects are strongly related to therise in microbial activity afier compost application. Hydrolyzed surplus organic carbon was exploited by microorganisms with the formation of excreted polysaccharides, natural binding agents for the cementing of soil aggregates and stability against irrigation (Xuan et al., 2023).

A higher impact was measured at site L1, which had slightly less initial gypsum (14.34%) than that of site L2 (17.43%). High gypsum levels can provide weak soil-cementation conditions that collapse with wetting easily (Poch et al., 2024). As a result, the compost and gypsum combination clearly enhances structural stability by counterbalancing to some extent the dispersive action of gypsum dissolution. The increase in bulk density observed here is consistent with the results of Tian et al. (2024) and Kavvadias et al. (2024) also found that between organic and gypsum are essential in improving the aggregate stability and decreasing soil strength of semi-arid soils. From a hydrological viewpoint, lower bulk density indicates better tractor traction, infiltration capacity, aeration and root penetration that are important for sustainable soil treatment of gypsum-soil landforms. In conclusion, the addition of composts led to significant improvements in soil physical properties through decreasing Pd at both sites, with an optimal rate for improvement between 5 and 7 t ha-1. Higher rates of application (10 t ha-1) did not produce additional significant reduction in bulk density because the bulk densities remained constant with excessive amounts of compost.

3.2 Effect of compost application on total porosity

The effect of adding compost on the total porosity (P) is shown in Table 4 and Figure 2 for gypsiferous soil. Results show total porosity clearly and consistently increased with increasing compost application rates in both locations at (L1 and L2). The control (0 t ha^{-1}) presented the lowest porosities, with values of 39.6% - L1 and 38.8% - L2. However, the highest compost application rate (10 t ha^{-1}) increased porosity to 46.4% and 45.6%, respectively. This rise indicates an overall enhancement of about 17% over the untreated soil.

Table (4): Effect of compost levels on total porosity (%) of gypsiferous soil under field conditions.

Site	Compost rate (t ha^{-1})	Total Porosity (%)	SD	% change vs control	Significance
L1	0 (Control)	39.6	0.8	—	a
	2.5	40.8	0.9	+3.0	ab
	5.0	42.8	0.7	+8.1	b
	7.0	44.4	0.8	+12.1	bc
	10.0	46.4	0.9	+17.2	c
L2	0 (Control)	38.8	0.8	—	a
	2.5	40.4	0.9	+4.1	ab
	5.0	42.0	0.8	+8.2	b
	7.0	43.6	0.9	+12.4	bc
	10.0	45.6	0.8	+17.5	c

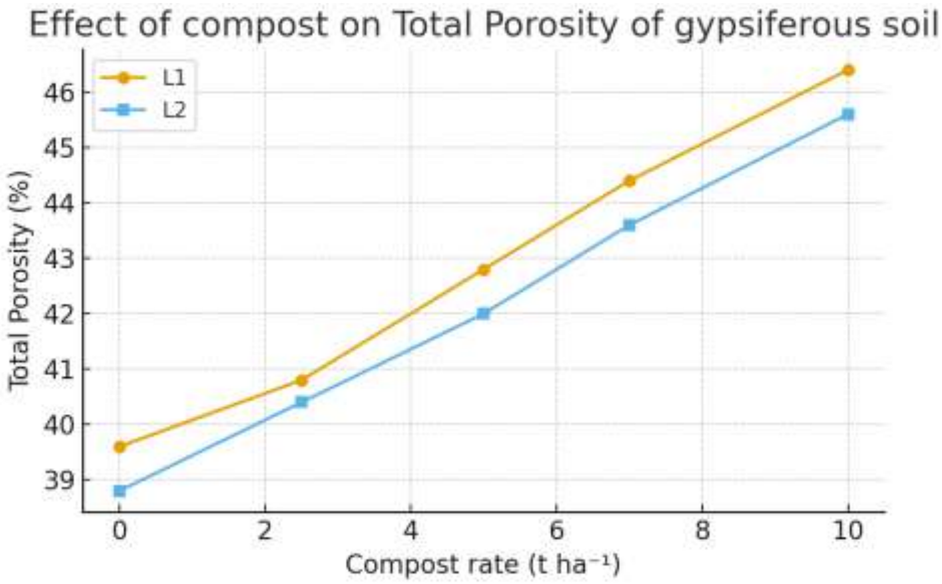

Figure (2): Effect of compost levels on total porosity of gypsiferous soil at two sites (L1 and L2).

The increase in total porosity as a result of compost treatment indicates an important form of improvement in soil stability and structural aggregates. This increased pore volume(on of air dry) can possible be explained by the addition of organic matter into the soil matrix reducing particle compaction and a more free structure. Compost is a stabilizing agent supporting the building of stable macropores and mesopores over organic bonding and activity of microorganisms (Kranz et al., 2020; Juan et al., 2023).

The observed 17% porosity increase also agrees with those of Castellini et al. (2022) and Bybil et al. (2022), that large alterations caused by compost addition substantially increased the macro porosity and overall stability of the dry soil, as well as improved infiltration and air-water balance.. Similarly, Mihalyykova et al. (2025) found that surface- affected compost increased soil porosity by 15-20% after a growing season, mainly due to improved stability of soil aggregates and reduced bulk density. At both ticrit sites, the porosity response pattern reflects the opposite trend to bulk density, in accordance with the mathematical relationship (P = 1 - Pd/Pd). However, the increase in porosity was slightly larger in place L1, which originally had a lower plaster content (14.34%) than L2 (17.43%). This suggests that the beneficial effect of compost was more pronounced in soil with less disruption of plaster during pore stabilization. Gypsal resolution and recrystallization can seal or weaken the pores, while the compost-derived organic matter counteracts such effects by filling the spaces with moist residues that resist sloping during watering (Poch et al., 2024; Tian et al., 2024). Hydrologically, higher porosity encourages better aeration and root growth which altogether help in water availability to plants. The macro and micropore ratio promoted by composting helps to enhance soil retention and crust reduction (Amer et al., 2023). These improvements are especially important for Gypsy soils which are usually saturated with water and compacted upon irrigation. Results reveal that compost application at rates of 5-7 tonnes ha(-1) result in the optimum structural enhancement by increasing porosity without inducing excessive stabilization. Higher rates of application (10 ha t-1) can continue increasing soil porosity but also may present the risk of temporary softening or waterlogging during periodic irrigation events. Thus, moderate levels of compost application are advised to contribute towards a continued enhanced physical quality but not loss of pore balance over the soil profile.

3.3 Effect of compost application on saturated hydraulic conductivity

The response of saturated hydraulic conductivity (Ksat) to compost application is presented in Table 5 and illustrated in Figure 3. Unlike bulk density and total porosity, the results revealed a gradual decrease in Ksat with increasing compost levels at both experimental sites (L1 and L2). The highest conductivity values were observed in the control treatment (85.2 cm h^{-1} at L1 and 82.8 cm h^{-1} at L2), whereas the lowest were recorded at the highest compost rate (68.3 and 66.9 cm h^{-1}, respectively). The decrease in Ksat at 10 t ha^{-1} reached approximately 20% compared with the control.

Table (5): Effect of compost levels on saturated hydraulic conductivity (cm h^{-1}) of gypsiferous soil under field conditions.

Site	**Compost rate (t ha^{-1})**	**Ksat (mean) [cm h^{-1}]**	**SD**	**% change vs control**	**Significance**
L1	0 (Control)	85.2	2.3	—	a
	2.5	82.4	2.1	−3.3	ab
	5.0	77.8	2.0	−8.7	b
	7.0	72.1	1.9	−15.4	bc
	10.0	68.3	1.8	−19.8	c
L2	0 (Control)	82.8	2.2	—	a
	2.5	79.5	2.0	−4.0	ab
	5.0	73.8	2.1	−10.8	b
	7.0	69.6	2.0	−16.0	bc
	10.0	66.9	1.9	−19.2	c

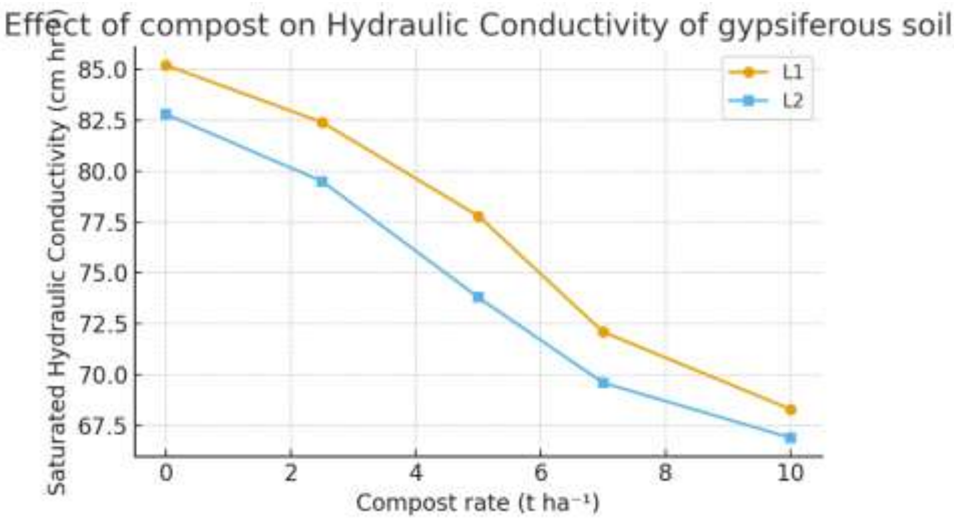

Figure (3): Effect of compost levels on saturated hydraulic conductivity of gypsiferous soil at two sites (L1 and L2).

The results indicated that Ksat of gypsiferous soil decreased significantly with enhanced compost application. While compost enhances aggregation and total porosity (Table 4), it also decreases macropore connectivity, which regulates the flow of saturated water. This trend is consistent with previous results in which the addition of organic material, and especially at larger rates, decreased Ksat by partly obstructing large pores and swelling of organics upon wetting (Castellini et al., 2022; Bayabil et al., 2022). Several mechanisms explain this behavior. The water stability of compost is higher than that of non-treated soils for two reasons:

(1) source material characteristic-the small organic particles of compost typically fill the larger transmission pores increasing meso- and micropore size distribution, or V(>0.3 µm), in comparison to Ups and Ss; (2) added C from compost can improve aggregation through enhancing microbial activity over time. It has increased water holding capacity and reduced hydraulic conductivity under near saturated condition (Xian et al., 2023). Second, humic substances are formed due to microbial degradation of compost, and they coat mineral particles and enhance the soil structure by stabilizing the larger pores (Miháliková et al., 2025).

These results are consistent with the study carried out by Amer et al. (2023) who found that increased fertilization decreased Ksat in gypsiferous soils by reducing macropore flow, but enhancing aggregation. Similarly, Tian et al. (2024) and Poch et al. (2024) reported organic matter increased soil structure, but under some irrigation condition may decreas e infiltration (especially when content of gypsum is highest). Decrease of Ksat by farm manure does not imply soil degradation but it indicates a shift from fast draining soil toward more 'normal' hydrology with less water-loss potential. Such adjustment can be advantageous in arid rather than humid climate, where a rapid direct infiltration results to deep percolation losses. Kranz et al. (2020) and Kavadias et al. (2024) indicated that reductions in hydrau lic conductivity in response to fertilization are moderate and potentially compensated by better water use efficiency and crop yields.

The decrease in Ksat at the two tikrit locations was similar but greater at site L1. This may be attributed to the initial low gypsum content, which made it easier for the compost to interact with SMC and more micropore developed and thereby stronger resistance characteristic of water saturation flow. However, high gypsum contents at L2 might have preserved some pathways of flow preference possibly through incomplete pore-sharing of organic matter.

In summary, the application of com post up to 7 t ha^{-1} represent the most favorable compromise between porosity increase and a moderate hydraulic conductivity, since at higher rates (10 t ha^{-1}) Ksat decreased further without additional benefits for soil physical properties. These results indicate that, under field irrigation, there are optimum levels of compost addition to enhance the physical and hydraulic properties of gypsiferous soils through increases in available water and a decrease in deep percolated losses.

CONCLUSIONS

The results of this research indicated that compost application enhanced the physical properties and structural stability of gypsiferous soil under field irrigation in the Tikrit area. The improvements were seen in terms of a decrease in bulk density and an increase in total porosity at both study locations (L1 and L2). Incorporation of the compost resulted in improvements in soil aggregation, pore continuity, and reduction in compaction that might be critical for root growth and physical characteristics affecting soil-water relations under arid-zone conditions. Conversely, the study showed that sKsat decreased linearly with increasing compost rates. This decrease was due to the partial clogging of macropores and a transition toward a meso- and micropore size distribution, with higher water retention but lower mean saturated flow rate. These agro-hydrological changes in hydraulic conditions may be favorable, particularly in arid and semi-arid regions where leaching and low water storage are the major problems. In general, it was concluded that the optimal compost application rates of 5-7 t ha^{-1} offered good trade-off between improved soil structure, increased porosity and satisfactory water conductivity. Increased rates of 10 t ha^{-1} did not further improve and reduce slightly permeability. Management From the management point of view, compost was confirmed as an efficient, sustainable amendment in order to improve physical soil fertility in gypsiferous soils and it is demonstrated that compaction is reduced and soil water efficiency for irrigation is increased. Further studies need to focus on the long-term effects of multiple compost applications, its interaction with gypsum-dissolution-related properties, and subsequent effects on crop production and hydraulic stability of soil.

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